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# KIMBERLY METHOD OF BLOCK-CAVING USING SLUSHER DRIFTS

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# KIMBERLY METHOD OF BLOCK-CAVING, USING SLUSHER DRIFTS[1/]

By John A. Richards[2/]

CONTENTS

| | Page |
|---|---|
| Introduction | 2 |
| Acknowledgment | 2 |
| Ore body | 2 |
| Methods of exploration | 3 |
| Evolution of slusher-drift methods | 4 |
| Mine openings | 6 |
| Haulage level | 6 |
| Raises | 6 |
| Standard slusher drifts | 7 |
| Mining practices | 7 |
| Drifts and finger raises | 7 |
| Undercutting | 9 |
| Slushing detail | 10 |
| Draw control | 10 |
| Slusher drift repairs | 13 |
| Slushing equipment | 13 |
| Scrapers | 13 |
| Ropes | 14 |
| Hoists | 14 |
| General | 14 |
| Advantages of slusher mining | 14 |
| Costs | 16 |

ILLUSTRATIONS

| Figure | | Following Page |
|---|---|---|
| 1. | General east-west section, Emma Nevada ore body, looking north | 2 |
| 2. | Procedure in high-lying ore bodies | 2 |
| 3. | Procedure in low-lying ore bodies | 2 |
| 4. | Method of development for slusher mining of extremely low-lying ores and those whose bottom contacts are from 10 to 60 feet above the main haulageway | 4 |
| 5. | Slusher mining at ore-body fringes | 4 |
| 6. | Standard slushing method for high-lying ores | 4 |
| 7. | Sublevel slusher-mining method | 4 |
| 8. | Haulage-drift set | 6 |
| 9. | Chute design | 6 |
| 10. | Slusher-drift segment set | 6 |

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2/ One of the consulting engineers, Bureau of Mines, and general superintendent, Consolidated Coppermines Corporation.

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ILLUSTRATIONS (Continued)


| Figure | | Following Page |
|---|---|---|
| 11. | Finger set | 8 |
| 12. | Draw slip as used at Emma Nevada mine | 10 |
| 13. | Main haulage level | 12 |
| 14. | Details of 42-inch scraper, Kimberly type | 14 |


## INTRODUCTION

This paper is one of a series being published by the Bureau of Mines on mining methods and costs. It describes briefly the manner in which slusher hoists and scrapers are used in connection with block-caving methods at the Emma Nevada mine of the Consolidated Coppermines Corporation, Kimberly, Nev.

Kimberly is in the Robinson mining district, White Pine County, 7 miles west of Ely. The district is served by the Nevada Northern Railroad, which branches from the main line of the Southern Pacific at Wells, Nev., 140 miles north. Paved U. S. Highway 50 from Salt Lake City, Utah, to Reno, Nev., passes through Ely. The altitude at the collar of the Emma Nevada shaft is 7117 feet. The surrounding hills are covered with a sparse growth of juniper, pinon, and mountain mahogany.

All mine timber and other supplies are brought in from a distance.


## ACKNOWLEDGMENT

Acknowledgment is made to Paul J. Sirkegian, assistant superintendent and chief engineer, Mark A. Smith, general mine foreman, and others for helpful suggestions and cooperation.


## ORE BODY

The principal ore body of the Consolidated Coppermines Corporation, which is serviced by the Emma Nevada shaft, is a gently undulating, south-dipping blanket of monzonite porphyry with a mineralized thickness of 60 to 400 feet; the average is about 175 feet. The overlying waste material is 200 to 500 feet thick. The ore body proper is about 3,500 feet long in an easterly and westerly direction and attains a maximum width of 1,200 feet. The copper mineral is chalcopyrite, which is distributed evenly through the mineralized area. The ore body is thoroughly fractured and altered and remarkably soft, which permits mining by a modified block-caving method. Virtually all the mineralized porphyry is underlain by a younger monzonite porphyry locally known as peanut porphyry, which in turn rests on a basement of sediments, either limestone or shale. The younger porphyry is fractured and altered less and generally stands better than the upper mineralized porphyry, although mine openings require heavy timbering in both cases. The waste material overlying the ore body is unmineralized porphyry, sedimentary pendants, and very irregular bodies of post-mineral rhyolite, which often intrude and may underlie or overlie the ore. The northern limit of the ore body as explored to date is formed by a zone in which diminution of copper values in the porphyry



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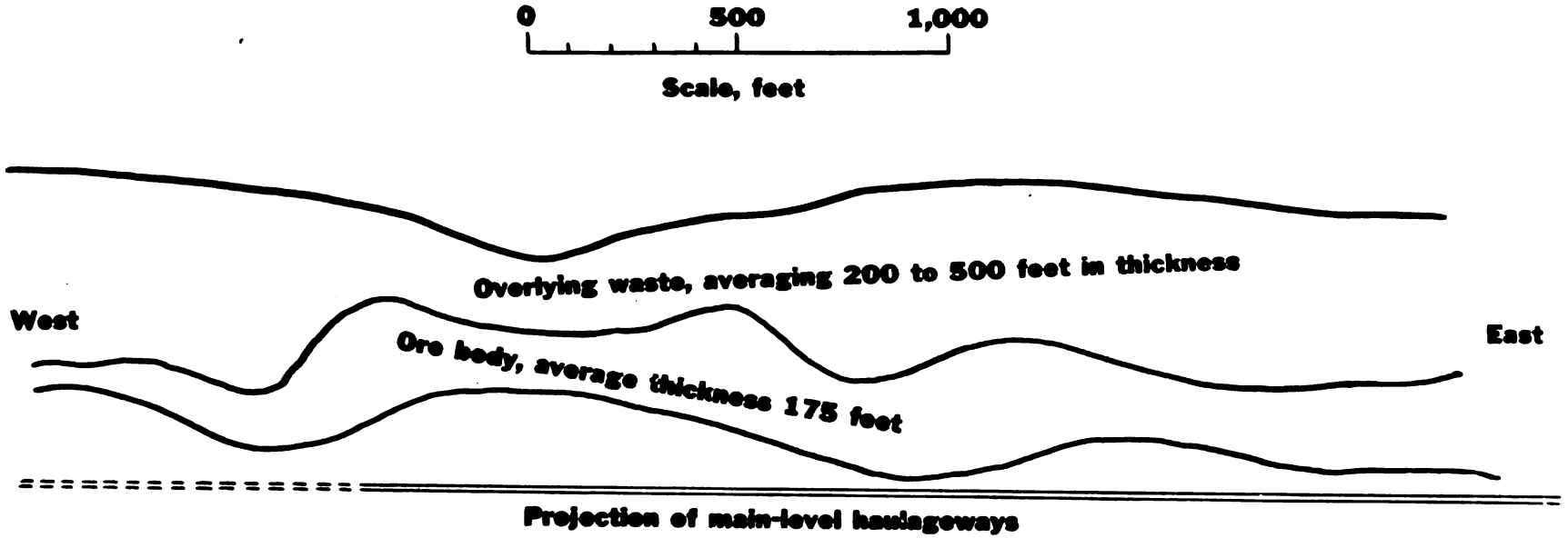


Figure 1.—General east-west section, Emma-Nevada ore body, looking north.

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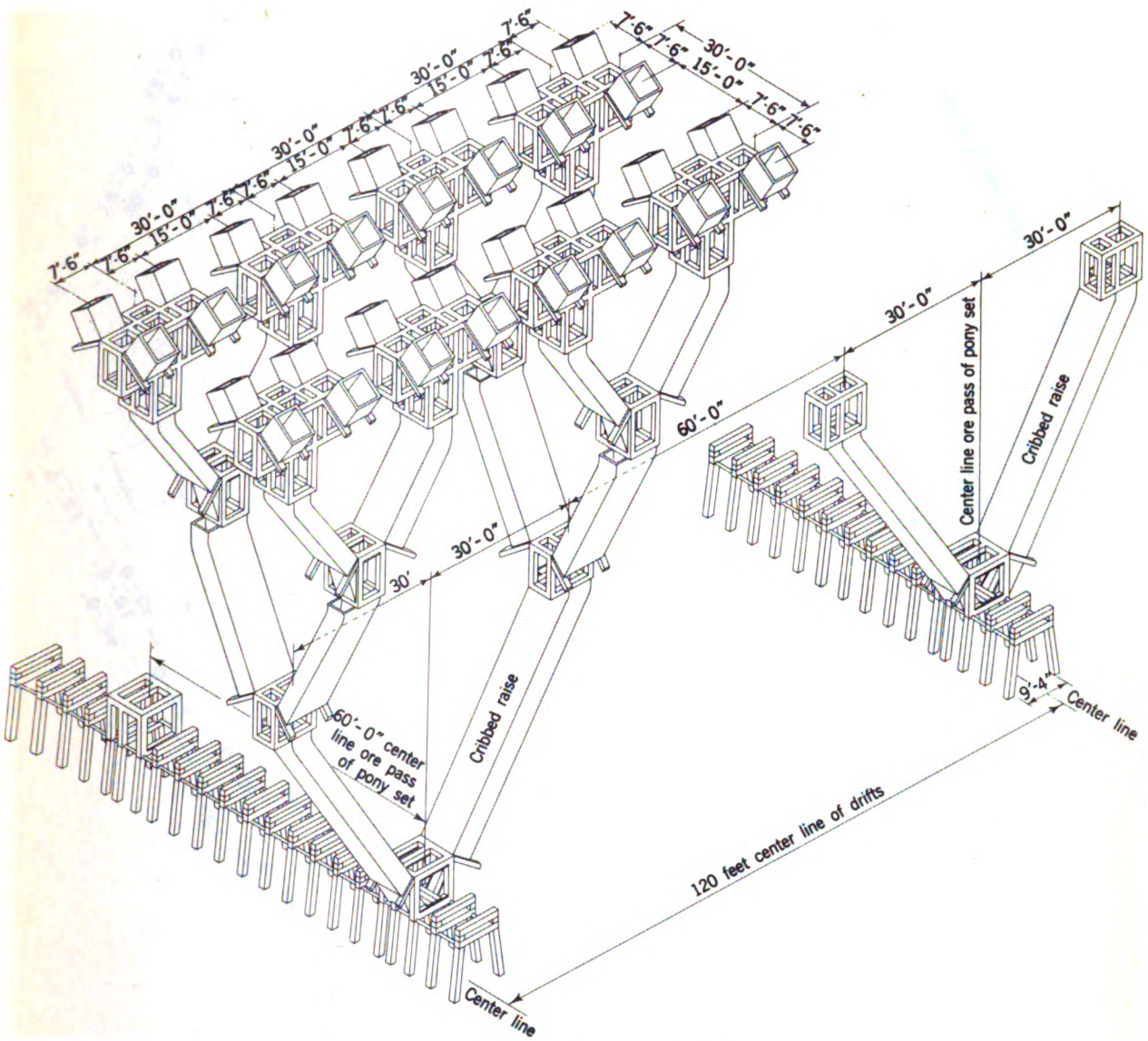


Figure 2.—Procedure in high-lying ore bodies.

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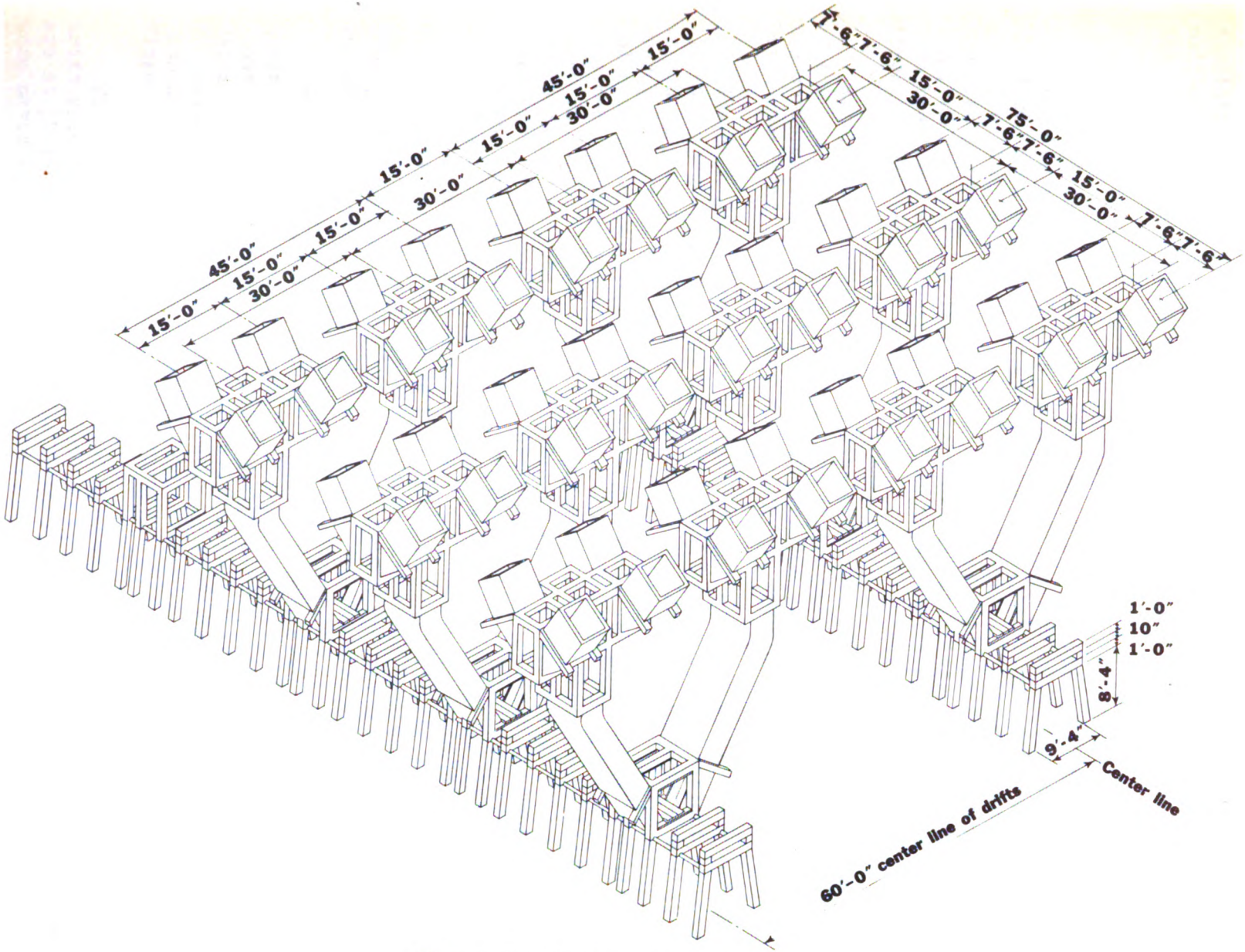


**Figure 3.—Procedure in low-lying ore bodies.**

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renders further mining uneconomical. The ore terminates to the south against the intrusive rhyolites. Shaft sinking began in the fall of 1926, when existence of approximately 7,000,000 tons of ore was established. Figure 1 is a generalized section through the ore body.

## METHODS OF EXPLORATION

Most of the ore body was explored by churn-drill holes from the surface with samples taken at 5-foot intervals. The churn-drill holes usually were about 200 feet apart, although the spacing of holes was governed partly by geologic study and partly by surface topography. Exploration by churn drills has been augmented to some degree by prospect headings from underground workings, short drifter drill holes, and diamond drilling. These latter methods have been used only to prospect fringe areas and to establish the location of irregular portions of the ore body.

After the churn-drill holes were completed and the top and bottom limits of the ore became known, contour maps of the ore body were prepared showing the conformation of the top and bottom of the ore. The mining layout is based upon study of the contour maps and the sections built up from them.

The Emma Nevada shaft is in the footwall of the ore body at a sufficient distance therefrom to insure against caving of the shaft and plant structures as mining progresses. The haulage level was driven at an elevation that averaged about 60 feet beneath the bottom of the ore body. Early mining followed the conventional block-caving method, using branch raises, which continues to be employed where particularly applicable. The ore body is mined in one lift, and the 60-foot interval left between the haulage level and bottom of the ore was established as the most economical distance for development purposes. A greater distance to the ore from the haulage level would mean less drifting but more raising; on the other hand, if a smaller distance were chosen, less raising and a greater footage of haulage drifts would be required. Although the ideal distance from ore to haulage drift is 60 feet, the bottom of the ore body undulates and often is step-faulted, causing this interval to range from zero, where the body dipped down to the level, to a maximum height of about 130 feet above the level. Such extreme variations, however, were rare and limited to relatively small areas.

The spacing of main haulage drifts and design of the branch raises were governed largely by the elevation of the bottom of the ore body. Figure 2 shows the type of raise used for high-lying ore bodies. When this method of raise development is used haulage drifts are extended on 120-foot centers and the raises are at 60-foot intervals along the drifts. This raise-development method follows closely conventional block-caving practices with the draw fingers spaced at 15-foot centers in both directions.

Figure 3 illustrates the method of developing the lower-lying ores. The drift spacing is reduced from 120 to 60 feet, and the raises in the drifts are at 30-foot intervals, but the 15-foot finger spacing is maintained. Drifts were never spaced closer than 60 feet; therefore, where the ore-body bottom



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approached the haulage level the branch raises pierced the ore, resulting in a part of the ore body being left below the undercut horizon. This ore, which was reclaimed later ranged in thickness up to a maximum of 60 feet from the haulage level to the undercut horizon. Scrapers and slusher hoists were first used in salvaging these unmined portions of the ore body, which, when broken, would not flow by gravity to the haulage drifts.

## EVOLUTION OF SLUSHER-DRIFT METHODS

Figure 4 illustrates the method employed at the Emma Nevada mine to reclaim ore below the undercut level. Pony sets were installed over the main drift caps at 30-foot intervals along the drifts. Crosscuts, now known as slusher drifts, were then driven from these pony sets just beneath the ore. Where the ore body was 15 or 20 feet above the haulage level, short raises were run from the pony sets to the ore and the slusher drifts driven at that horizon. The slusher drifts were timbered with 12- by 12-inch drift sets on 5-foot centers. Short, cribbed fingers were installed at every third drift set, thus maintaining a 15-foot finger spacing. The tops of these fingers were connected by undercutting. Where slusher drifts were driven from the pony sets at the same elevation, the ore was drawn through the fingers into the drifts and scraped directly into ore cars. Where a short raise extended from the pony set to the slusher drift, the ore was dragged into the raise; a chute with an arc gate was provided for loading the cars. The length of a slusher drift was limited to 60 feet, as the main haulage laterals had been driven on that spacing. As portions of the ore body left below the branch-raise undercut horizon were mined successfully by this method, it therefore seemed logical, when the bottom of the ore body was close to the level, to dispense with the branch raises and attempt to mine the entire thickness through slusher drifts. Such a procedure in virgin areas would save the cost of the branch raises and one undercutting operation.

In the latter part of 1937 it was decided to develop a trial block for slusher mining. An area was chosen where the bottom of the ore body was 15 or 20 feet above the haulage level. The block developed lay between two haulage drifts 180 feet apart; slusher drifts were driven on 30-foot centers at the bottom of the ore between these drifts. (See fig. 4.) Slusher hoists were installed at each end of the drifts, giving a slushing distance of 90 feet. Many difficulties were experienced in mining this trial block. The block was mined successfully, however, at a cost comparing favorably with the old practice, and a remarkably good recovery of ore was made. The possibility of applying this method of mining to other areas was next considered. A section along the north fringe of the ore body had been mined by using branch raises early in the life of the mine; the situation shown by figure 5 was left. This portion of the ore body had decreased in thickness and copper tenor to such an extent that the cost of mining through raises from the main level was prohibitive. A method of development was devised that utilized the raises that had already mined the overlying ore and that had since been abandoned. Slusher drifts were driven northerly at 30-foot intervals from the abandoned raises, as shown on figure 5. As the drifts advanced and fingers were installed, an occasional prospect raise was extended from the



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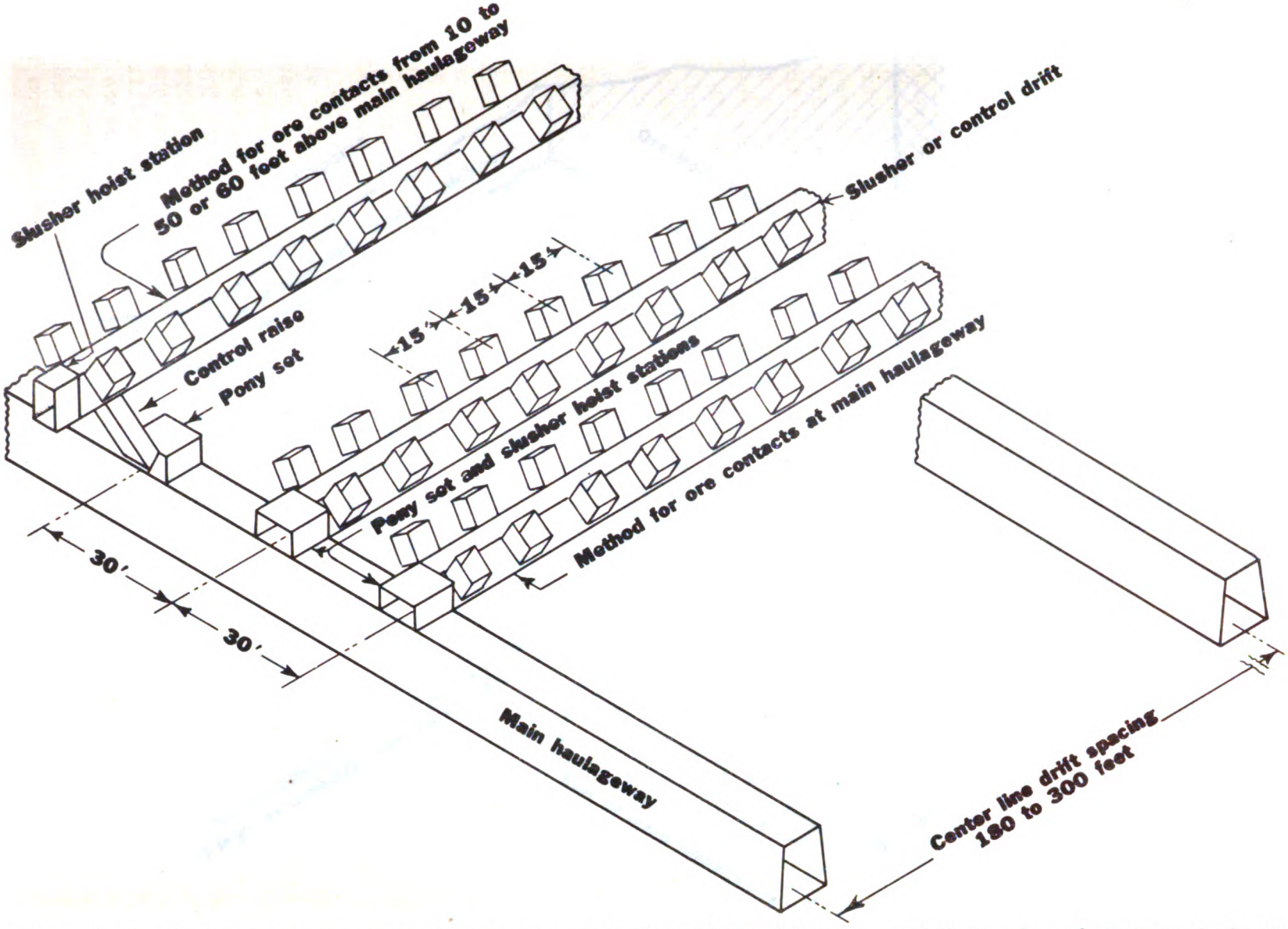


**Figure 4.– Method of development for slusher mining of extremely low-lying ores and those whose bottom contacts are from 10 to 60 feet above the main haulageway.**

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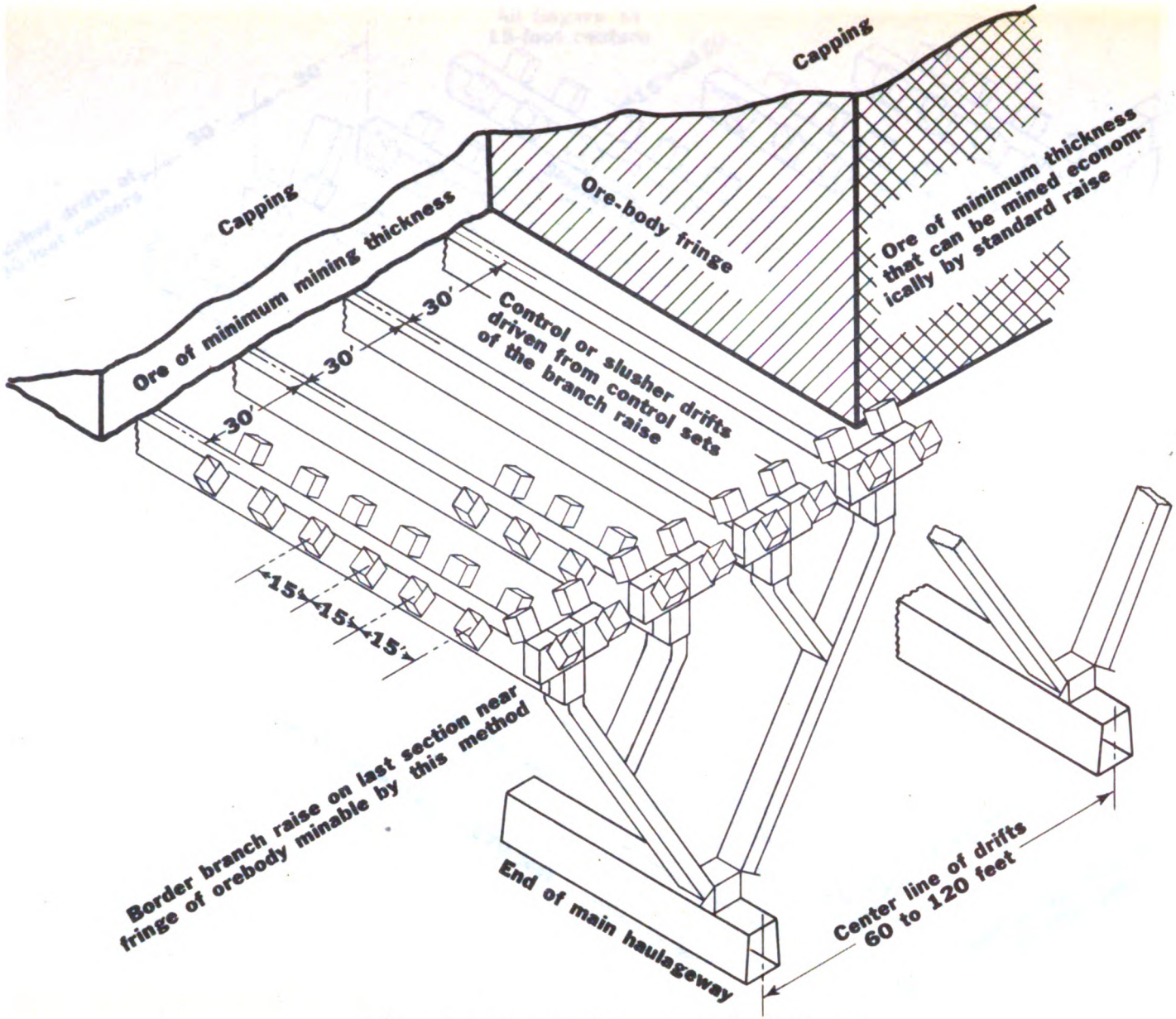
Capping
Capping
Ore-body fringe
Ore of minimum thickness that can be mined economically by standard raise
Ore of minimum mining thickness
30'
30'
30'
Control or slusher drifts driven from control sets of the branch raise
15'
15'
15'
Border branch raise on last section near fringe of orebody minable by this method
End of main haulageway
Center line of drifts 60 to 120 feet

Figure 5.—Slusher mining of ore-body fringes.

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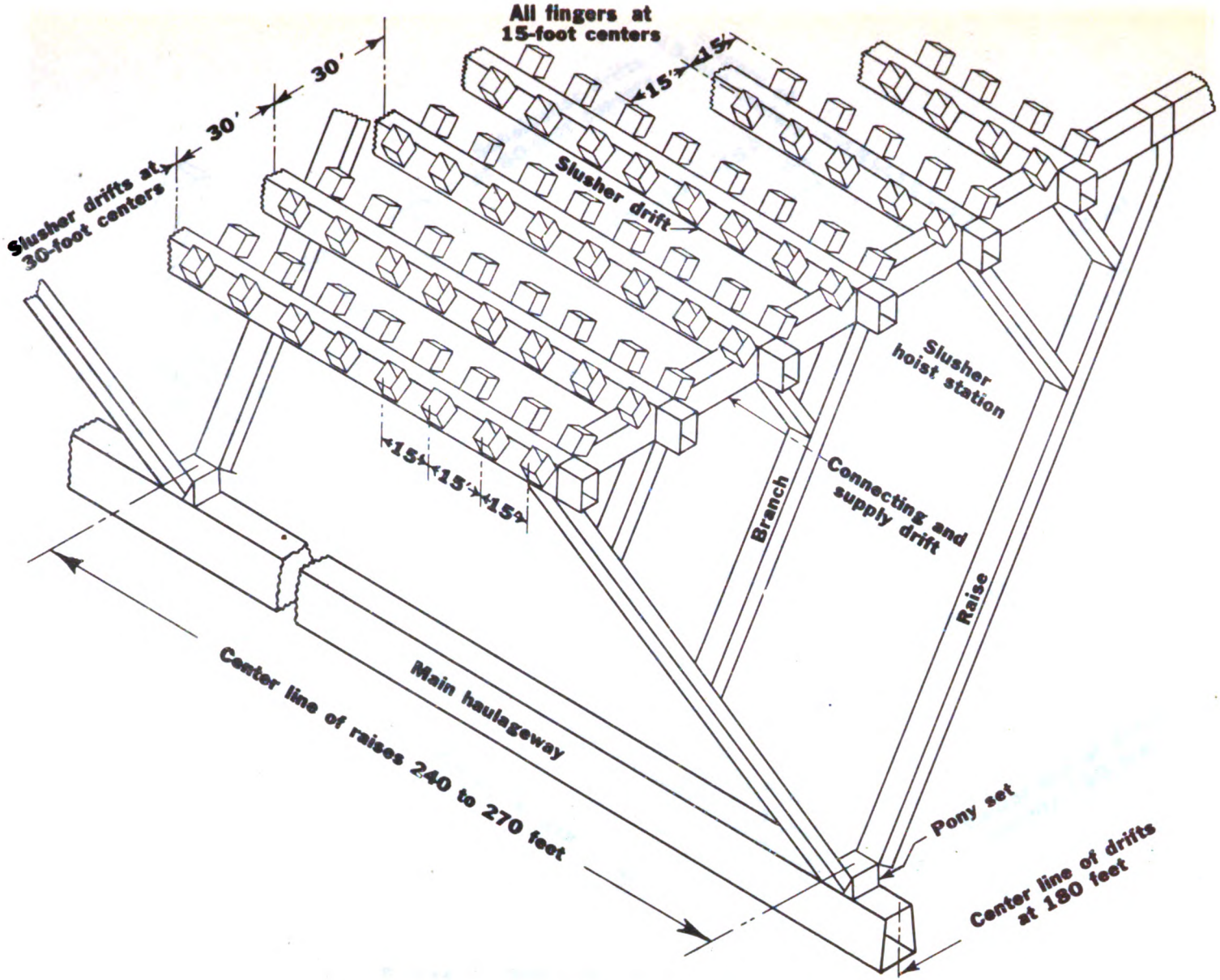


Figure 6.— Standard slushing method for high-lying ores.

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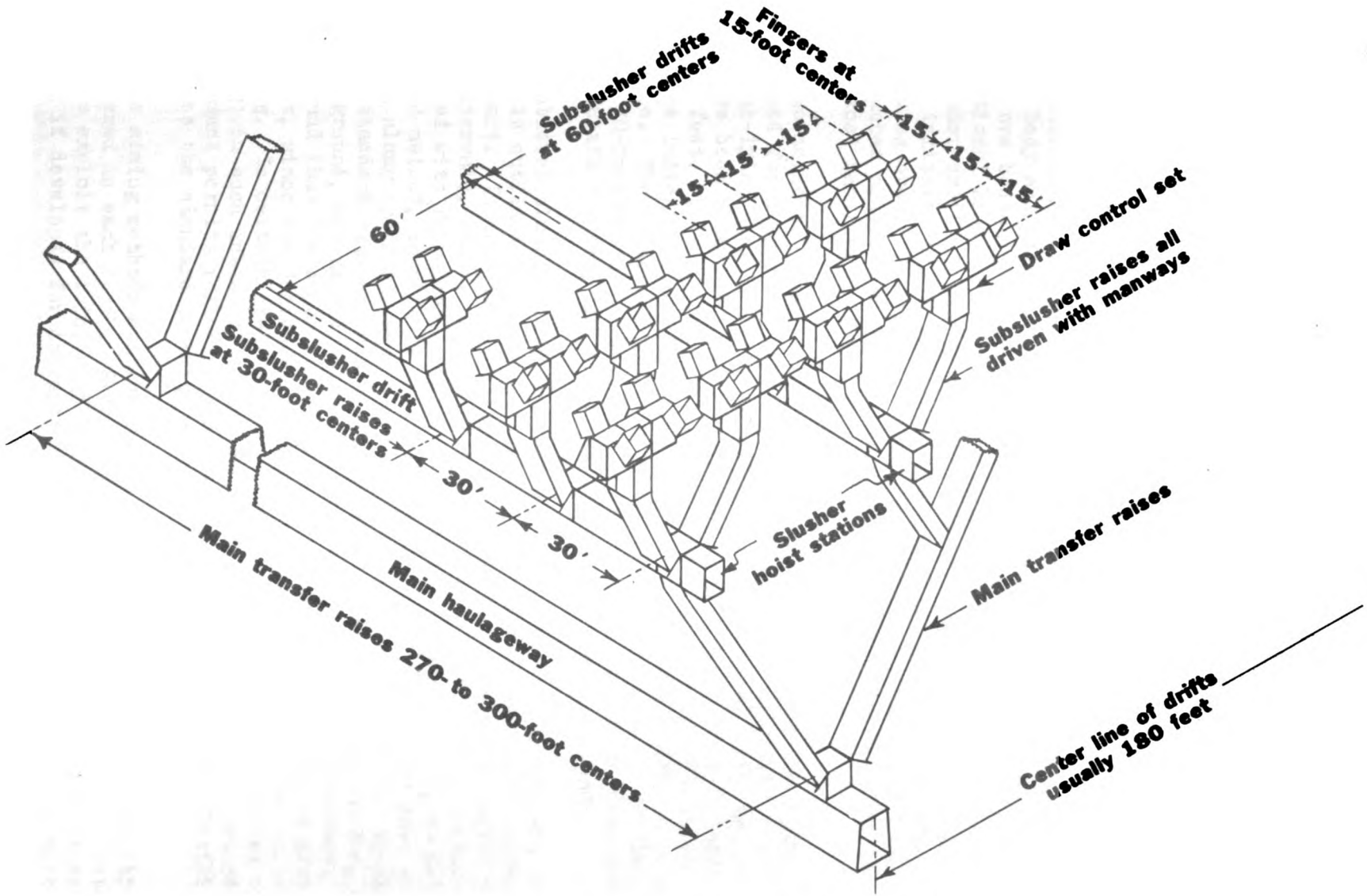


**Figure 7.— Sublevel slusher-mining method.**

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fingers through the ore. If enough ore was shown to justify development and mining the drift was advanced. By this method the ore body was explored and developed in one step. This application of slusher mining has since been extremely useful in fringe areas, as the maximum amount of ore is recovered and the necessity of expensive churn drilling or other preliminary exploration is eliminated.

Continued exploration by churn drilling had disclosed that, in addition to the 7,000,000 tons recognized when the shaft was sunk and the haulage level established, there was a large tonnage of ore to the west. This westward extension of the ore body lies at a higher horizon than the main portion of the body and often is 200 feet above the established haulage level. These higher ore bodies were expensive to develop from the haulage level by the conventional branch raise methods. A comparison between the costs attained by slusher drifts in the fringes and low-lying areas and the branch-raise method indicated that the slusher method might be used to advantage in the high-lying ores. Studies indicated that the savings in development by applying slusher practice would more than offset any increase in cost incident to mechanical handling of the ore.

Two methods, known as standard slushing and sublevel slushing, were developed for extracting high-lying ores. Standard slushing as applied to the high-lying ores is illustrated by figure 6. Raises from the main haulageway have been placed 240 to 270 feet apart, giving slushing distances of 120 to 135 feet. This distance has been exceeded in some instances, but present practice indicates that 120 to 150 feet is the economic limit of slushing distance. The raises branch to give openings at or near the bottom of the ore on 30-foot centers. The slusher drifts are driven from these raises just beneath the ore, and fingers are installed spaced 15 feet.

Sublevel slushing also has been applied in several areas, and the general method is outlined in figure 7. In this method the subslusher drifts are 60 feet apart. Intermediate raises are run from the subslusher drifts at 30-foot intervals, and at the top of these raises a conventional control set is installed with four draw fingers. This method of development, as well as the standard method, results in a finger spacing of 15 feet. The main raise spacing along the haulageway may be increased somewhat over the spacing used in the standard slusher method, as the subslusher drifts are longer, are in better ground, and usually stand better, requiring less maintenance. It has been found that the slushing distance in the subdrifts can be as great as 150 feet, since the decreased maintenance work allows more time for actual slushing. In certain areas the ore-body bottom may be step-faulted or steeply dipping; in such instances it has been found that the sublevel method of development permits following the actual ore bottom with more flexibility than does the standard slushing method.

The mining methods must be varied to suit the particular conditions encountered in each block. Slusher mining is the most economical method devised to exploit the thin, high-lying ores, which would require excessive raising if developed for conventional block-caving methods. The cost of



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mechanically moving the ore must be balanced against savings in development costs, but when the ore body is thin these savings more than offset the cost of slushing the ore.

Before a final decision is made on the mining method to be used in a block, a comparative analytical study is made of available data. Plate-glass models showing proposed development layouts, motor haulage drifts, and the ore-waste contacts are constructed. These models aid in solving the development problems, which otherwise would be difficult to visualize. In one particular block preliminary estimates showed a cost of 26.8 cents per ton for development by standard raises, 18.7 cents for development using subslushing methods, and 16.2 cents for development by standard slushing methods. This block was located at a place where the ore-body bottom was 200 feet above the level and the ore averaged 125 feet in thickness. When the ore body is closer to the level and of greater thickness the development savings are smaller, and in some instances conventional block-caving methods are used. Thus far conventional block-caving has been applied where the ore body is thick and 60 to 100 feet above the haulage level. At the time of writing (November 1939), the mine is yielding about 70,000 tons per month by standard slushing, 80,000 tons by subslushing, and 30,000 tons by conventional block-caving methods.

## MINE OPENINGS

### Haulage Level

As virtually all of the ground in the Emma Nevada mine is extremely soft, heavy timbering is required to support most mine openings. Drifts and raises are kept as small in cross section as is practical for handling large tonnages. Timbering in the main haulage drift and extraction laterals consists of a cap 6 feet 6 inches in the clear, which is bridged and spiled in heavy or swelling ground; and posts that are 8 feet 8 inches long on the dry side and 9 feet on the ditch side. The posts generally are set with a batter of 1-3/4 inches per linear foot of post, which may be varied as ground conditions change. Twelve- by twelve-inch Douglas fir timber is used for caps and posts and split lagging for top and side lacing. Figure 8 shows the standard drift set with bridge. Figure 9 shows the pony set and chute arrangement. Ten-ton trolley locomotives and drop-bottom cars with a 5-1/4-ton pay-load capacity constitute the haulage equipment. The track is 75-pound rail and has a gage of 36 inches.

### Raises

All raises are cribbed, the timber size being determined by the character of ground and the tonnage that is to pass through the raise. Where the ground stands fairly well, 4- by 12-inch cribbing generally is used, although 6- by 12-inch timbers may be installed where a raise is expected to accommodate a large tonnage and consequently will be subjected to excessive wear. In heavy ground, 6- by 12-inch or 6- by 8-inch cribbing on 6-inch spacing blocks is commonly used.



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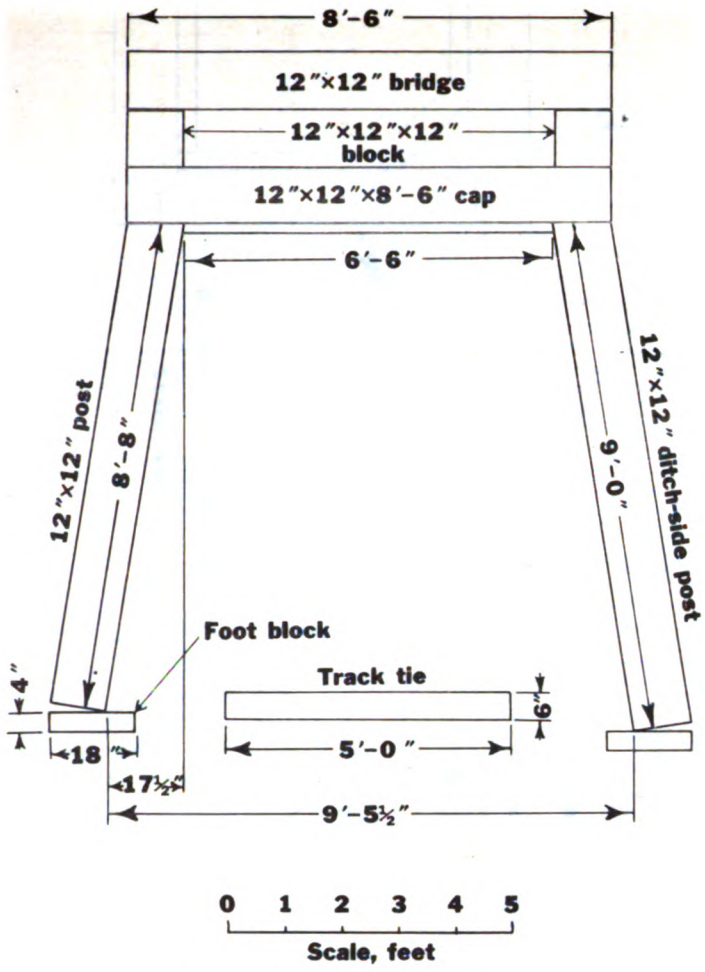


Figure 8.– Haulage-drift set.

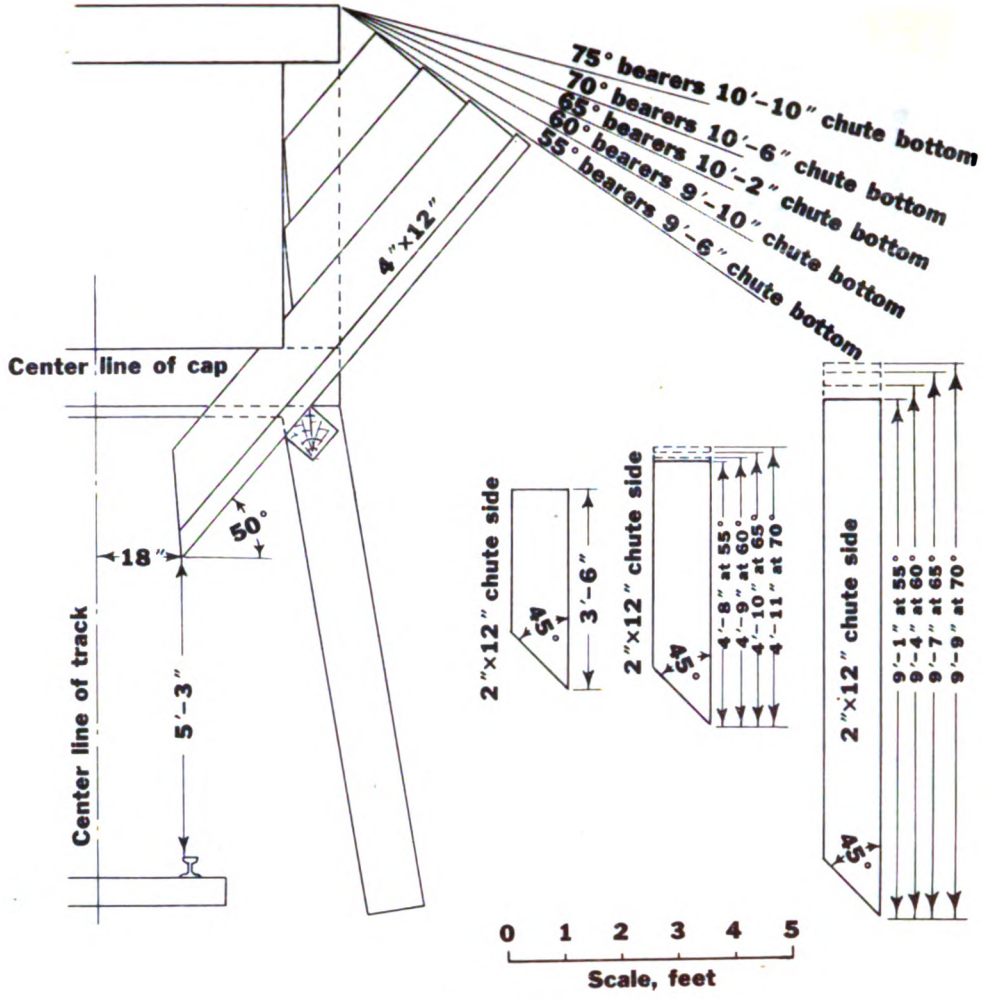


Figure 9.– Chute design.

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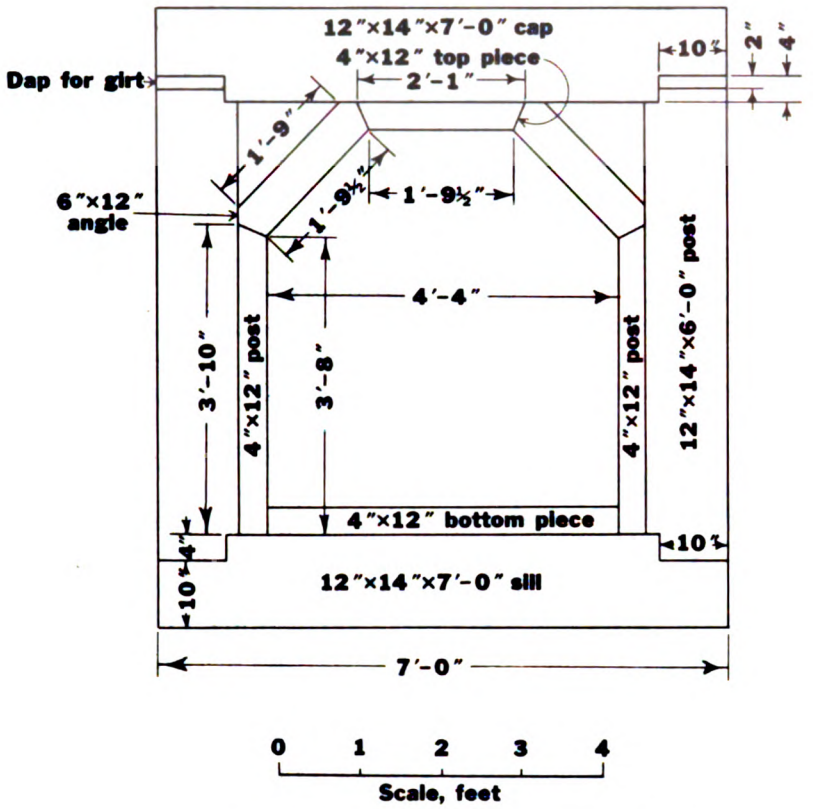


Figure 10.– Slusher-drift segment set.

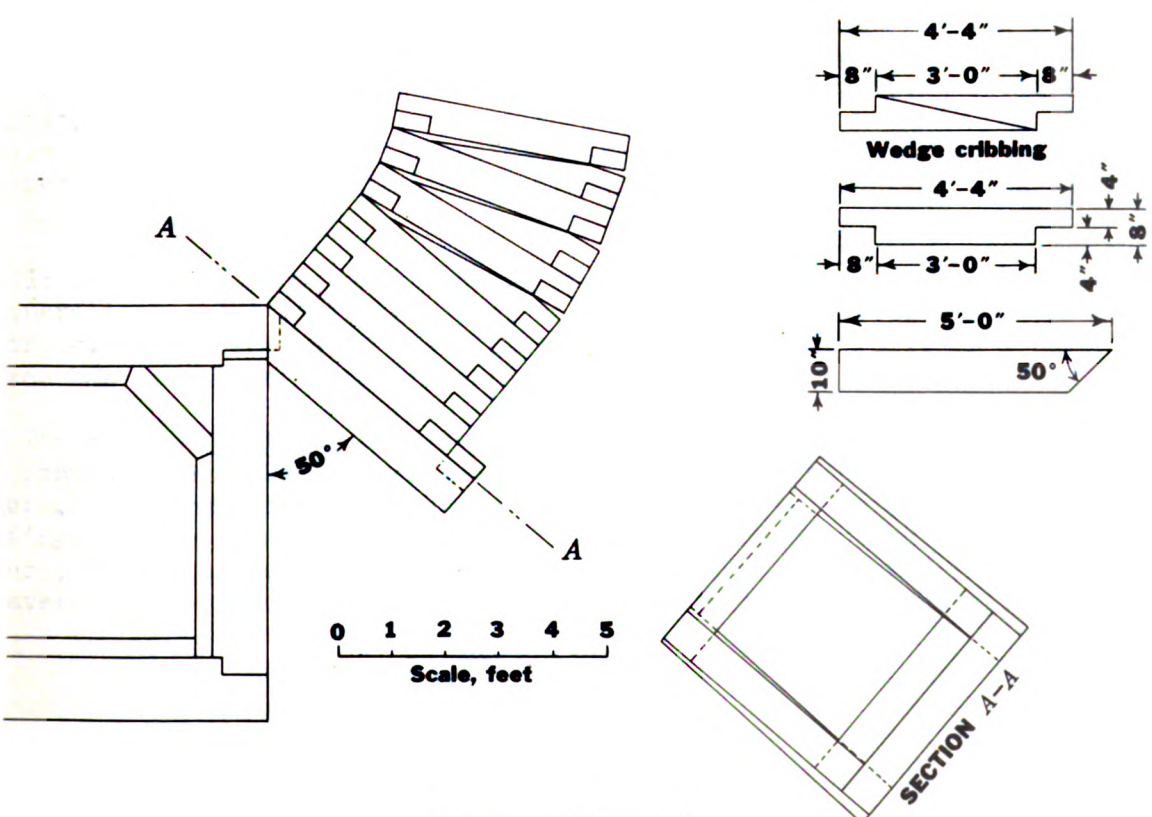


Figure 11.– Finger set.

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Where conventional block-caving is used, the chute compartment is 3 1/2 by 3 1/2 feet on the inside; the manway compartments have inside dimensions of 2 feet 2 inches by 3 1/2 feet. In slusher mining a raise must serve about eight times the tonnage handled in conventional cave mining, and for this reason the manway and chute compartments are made the same size and are interchangeable. The compartments are 4 feet square inside and lined on all sides with 2-inch lagging. Large tonnages pass through the slusher raises daily and prolonged delays for repairs would be costly. If the chute compartment has to be repaired, the manway can be converted quickly into a chute by taking out the ladders and installing a gate in the pony set. The manway compartment has ample room to accommodate the ladderway and a slide for hoisting timbers and other supplies.

Although hand-operated arc gates are used in the conventional mining raises, air-lift, down-cut, vertical gates have been installed for the slusher raises where much larger daily tonnages must be loaded. The air gates speed loading and reduce loading costs materially. One man on an air gate has loaded up to 2,000 tons in a single shift.

### Standard Slusher Drifts

Figure 10 shows a standardized slusher-drift segment set. The sets are placed on 5-foot centers except at the fingers, where a 4-foot interval is used. The posts are plumb and are of 12- by 14-inch timber 6 feet 2 inches long. The drift caps and sills are framed the same and are interchangeable; they are of 12- by 14-inch timber and 5 feet inside the frame. An important feature of this set is the 12- by 14-inch sill. Light sills failed as rapidly as they were put in, and the posts were driven down and pushed in at the bottom. Most failures occurred in former sets at the junction of the sill and post, which is a difficult place to relieve when the muck is pushed in between the posts during the slushing operation. The present drift set is designed to overcome this particular difficulty. Split lagging is used for tops and sides.

It is of paramount importance to provide a good drift bottom for slushing operations. The sill must be strong enough so that it will not buckle and break. The practice of installing three light steel rails as a scraping surface has proved very satisfactory.

The drift and finger crew consists of three miners, who work on a cooperative bonus system. Generally, two men work in the face and one man on the fingers. The crew usually advances the face 5 feet per shift, and the man on the fingers keeps pace with the drift crew. The miners place all of the timbers, including segment sets and a temporary 2-inch floor for scraping. The average time required to slush out a drift round is 40 minutes.

## MINING PRACTICES

### Drifts and Finger Raises

The peanut porphyry immediately below the ore is quite soft and badly fractured. The ore-waste contact is nearly always marked by horizontal shearing and a gummy plastic material known locally as chewing-gum gouge.



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Layers of this gummy material may comprise 2 to 15 feet of the rock immediately beneath the ore, and in some cases 10-foot thicknesses of gouge have been found. In the first blocks mined by slusher methods, difficulty was experienced in maintaining the slusher drifts, particularly when this gouge was encountered. Much thought has been given to choosing the best locations for these drifts.

The success of slusher mining hinges almost entirely on the design, excavation, and maintenance of the slusher drifts and draw fingers. The best horizon for the drifts in the Emma Nevada mine is about 10 feet below the ore-waste contact. As the bottom contour of the ore undulates, slusher drifts are laid out to strike this distance as an average. It has been found necessary to keep the drifts nearly horizontal; the maximum grade used is 4 inches per 5-foot set. In grades steeper than this the drift sets ride upgrade and are difficult to maintain. Where the ore-bottom contour dips steeply or is step-faulted, ideal lay-outs are not possible. The ore may be 25 or 30 feet above the drift at one end and may dip down into the drift at the other end. This irregularity is met satisfactorily in the finger detail and salvaging operations. Where the ore is high above the drift the fingers are extended up to the ore contact. The excavated material is handled as waste where the drift or fingers are below the ore. The fingers have a minimum length of 10 feet above the cap, 5 feet of which is timbered. Any cones of ore left between the fingers are recovered as a salvage operation after the fingers have been drawn to completion.

When a raise for standard slushing has been completed and the cribbing leveled off at a point generally about 18 feet below the ore, a chute and manway set are installed on top of the raise. The tugger station next is excavated and timbered, and after two or three drift sets are placed the tugger hoist is set up to scrape the spoil made in drifting into the raise.

To minimize maintenance it has been found essential in slusher drift and finger excavation to keep overbreaking at a minimum, and the development crews are penalized if they overbreak where it is avoidable. By careful development the pillars between the slusher drifts and the cones between the draw points are kept to a maximum size, which aids materially in supporting the overlying weight and in reducing repair costs.

The draw fingers are placed on 14-foot centers along the slusher drift and constructed of 8- by 8-inch cribbing resting on 10- by 10-inch bearers. The fingers are 3 by 3 feet inside and installed at a 55° angle from the horizontal. Figure 11 shows the finger set. The timbered portion of the finger extends 4 feet above the drift sets. If the fingers are in ore, one vertical round is taken out above the cribbing and is belled out on the footwall side. If the fingers are in waste, they are extended up to the ore without cribbing and the last round is belled out on the footwall side.

The finger is designed so the chute blaster can punch the ore down or blast the finger from the drift. Long cribbed fingers were tried in the early stages of slusher mining, but the cribbing was crushed or blasted out and maintenance was excessive. It was also found to be too hazardous to climb into long fingers in case of hang-ups.



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The length of the slusher drifts has a direct bearing on the economy and success of the method, as savings in main level and raise headings are increased as the slusher drifts are lengthened. It has been found that about 120 feet is the most economical length, and 150 feet is the maximum. Where ground conditions are bad and much repair work is necessary, it is impractical to have drifts longer than 120 feet as the collapse of a portion of the drift takes too great an area out of production while repairs are made. All the slushing is done on one shift at the Emma Nevada mine, leaving the other shift free for repairs. The amount of ore that can be slushed in one shift through a 120-foot drift is used as a control figure for mining in that area. The length of the slusher drifts may be increased for very thin ore bodies, as the drifts will have a shorter life and heavy repairs may not become necessary.

## Undercutting

The method of undercutting is designed to keep as much solid ground as possible between the top of the draw point and drifts to protect the drifts from excessive weight. All undercutting is done with self-rotating stopers, and all holes are drilled at 45° or steeper. This results in pyramids of solid material being left between all draw points. Careful supervision is necessary so that the undercut may be complete with no pillars left. These pillars would throw undue weight on the drifts and fingers and cause piping when the ore was drawn. It is considered as important not to overbreak into adjacent virgin ground as it is to underbreak and leave pillars. Drawings are furnished the undercut bosses and the instructions are rigidly enforced. The weakest point in the ore body is near the contact, and undercutting must be rapid to prevent caving, which might drive out the crew before the undercut is complete, so that pillars are left.

The undercutting is done on a bonus system, and a crew consists of two men. An average of about two shifts is required to complete a unit, which comprises one pair of fingers or 450 square feet.

Undercutting is begun above the back end of the drift and retreats to the main raise, always breaking to the cave. The first stage in undercutting, where the finger is in ore, is to drill two raise rounds and bell out the last round. If the finger is in waste, it is extended up to the ore and the last round is belled out. The second stage is to connect the fingers by inclined connection drifts that parallel the slusher drift. This connection is made with as large a cross section as the ground will permit to take care of the swell when the final round is blasted. The last stage in mining is to drill out the back and pillars from the inclined connection drift, using eight radial rounds, 4 feet apart, of five holes each. It has been found impractical and unsafe to partly undercut large areas and shoot out a large group of pillars at once.

As the ore is very soft and thoroughly cross-fractured, cut-off stopes are necessary only in exceptional instances. In the harder portions of the ore body or in blocks bounded on all sides by virgin ground, very short shrinkage cut-offs are used in the corners of the block.



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When the undercutting is completed, a bottom slice of ore 30 feet wide, 8 feet or more high, and the length of the slusher drift has been removed.

## Slushing Detail

As soon as the undercut is blasted miners begin drawing ore. The newly undercut fingers often have pockets of gas trapped behind the ore in the fingers; because of the danger of one man being overcome by gas and not being rescued immediately, two men work together. Much hand augering and blasting are necessary to induce a recently undercut area to cave, and this also requires two men. At this period in the life of a slusher drift, both shifts are occupied in drawing the broken ore. Within a few days the newly undercut block starts caving, and normal operations are begun.

When a block has finally been induced to cave by drawing the blasted material out of the undercut portion, all drawing and slushing in each slusher drift are done on one shift by two miners. The repair and maintenance work is performed on the opposite shift. Two men constitute a repair crew, and the mine safety rules require them to work within sight and sound of each other. The number of repair crews necessary depends on the amount of work to be done in each place. Under ordinary conditions three repairmen, or one and a half crews, handle all the mining and repair work for any slusher drift.

Since pulling ore and repairing are specialized jobs requiring a practiced routine and a developed skill, an attempt is made to keep the trained men on their specialized jobs. As a general rule the younger, more agile men become better slusher operators, while the older and more experienced miners do the maintenance work.

Interesting experiments planned for the near future include a trial block using a 30-horsepower hoist for cross slushing to effect further development savings and installation of a shaking conveyor to replace the hoists and scrapers in the slusher drifts.

## Draw Control

The success of a caving method of mining depends directly on an efficient practice of drawing the ore; the maximum recovery of ore with minimum dilution of waste is sought. Sound knowledge of the mechanics of caving combined with experience and close observation and systematically recorded data are the prerequisites for success. At the Emma Nevada mine every means is taken to insure the proper draw of ore and to record the data so that they can be interpreted readily.

One of the best aids in the drawing procedure is a plate-glass model, which is made for each block. Various types of models, charts, and graphs were tested before the glass model was tried. The plates represent 30-foot vertical sections, and each block has four to eight glass sections. The plates are held at the base by grooved blocks. The scale used on the sections is 20 feet to the inch.



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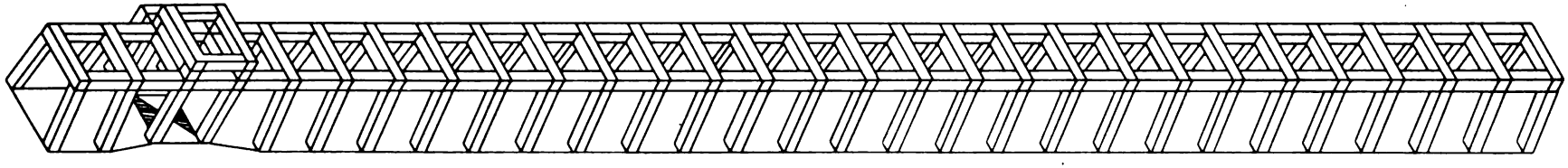
Check No. _ _ _ Condition of: Motor _ _ _ _ Cable _ _ _ _ _ Scraper _ _ _ _ _ Number of cars _ _ _



Drift No. _ _ _ _ _

**Figure 12.—Draw slip as used at Emma-Nevada mine.**

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The development openings are shown on the bottom portion of the sections and the top and bottom contours of the ore depicted above. The ore is shown in solid red by spraying the color on the glass plates; the development workings are in black. At 10-day periods a portion of the red color corresponding to the height of ore that has been drawn out is scraped from the plates. These plate models have an advantage over other models in that the relative positions of the draw points are in full view. Of course these models are valueless unless they are kept strictly up to date. The drawing procedure is under direct supervision of a draw-control boss, who has charge of and is assisted by the samplers. The draw boss, samplers, mucker bosses, and foreman all work in close harmony.

At the beginning of a shift each slusher operator is given a draw slip, which is a printed small-scale drawing of the slusher drift. The number of cars to be drawn is marked on each finger, and any special instructions are written on the slip. At the end of the shift the slusher operator fills in the number of cars actually drawn from each finger. The slusher operator keeps track of the number of scraper loads from each finger and a factor is used to convert number of loads into cars. Figure 12 shows a copy of a standard slusher draw slip.

The fingers are constructed in such a way that the broken ore is under control at all times. Each time the slusher operator punches down a finger, about three scraper loads or 2.1 tons of ore run into the drift. Over a period of time all the fingers will average about three scraper loads for each time they are drawn. The slusher operator always begins drawing the fingers from the back end of the drift. Since the full length of the drift is visible, the supervisors immediately investigate if any finger is not being drawn. With the slusher method of mining, control of the draw is ideal; this conclusion has been borne out by the excellent recovery of ore with a minimum amount of dilution.

An average slusher mining drift has 14 fingers; with a draw of 20 tons per finger, the daily production for a drift is 280 tons. This tonnage is mined each day in a series of cycles consisting of a slushing period and a finger-pulling operation.

The slushing operation lasts 15 to 35 minutes, during which time the slusher will handle approximately 1 ton of ore per minute. Each trip of the scraper moves 0.7 ton of ore an average distance of 75 feet, requiring 40 seconds to complete the round trip, including loading and dumping. The slusher operator soon becomes expert; an average of about 2 seconds is required to load the scraper. The load is dumped with virtually no more time lost than is required in the process of reversing the direction of the scraper.

The finger-punching operation, which begins when the drift is slushed clean of ore, lasts 10 to 20 minutes. The ore packs easily, and a finger seldom runs for any length of time without punching. The miner starts on the last pair of fingers in the slusher drift and bars down the ore into the drift, working the fingers back toward the tugger. His main tool is a bar 5 to 7 feet long made of 1-inch pipe forged to a point at one end. A finger may hang up for one of two reasons - either it becomes packed or the coarser ore becomes tightly wedged. The packed condition is alleviated by drilling



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hand-auger holes and blasting. The wedged boulders are blasted by bombs made of a number of sticks of dynamite tied to the end of long, light, blasting sticks and placed tightly between the boulders. The finger-drawing and slushing cycles are continued each shift until lunchtime unless hung-up fingers must be blasted earlier. Plugged fingers generally are blasted at lunchtime.

The following tabulation shows an idealized slushing shift:

| A.M. | | Production, tons |
|---|---|---|
| 7.50 | Arrive in slusher drift and slush ore blasted down at the end of the previous shift by repair crew. | 25 |
| 8.14 | Punch fingers | -- |
| 8.24 | Slush | 31 |
| 8.54 | Punch fingers | -- |
| 9.04 | Slush (fingers continue to run well) | 31 |
| 9.34 | Punch fingers (more time required because packing is beginning) | -- |
| 9.48 | Slush (fingers run less ore) | 25 |
| 10.12 | Punch fingers (some fingers full of boulders; others packed) | -- |
| 10.27 | Slush (fingers run poorly) | 15 |
| 10.42 | Drill auger holes in packed fingers | -- |
| 10.57 | Go after powder and primers | -- |
| 11.07 | Load auger holes and place bombs between boulders | -- |
| 11.20 | Spit shots and go to lunch. Smoke and gas clear out | -- |
| P.M. | | |
| 12.05 | Slush ore blasted down | 31 |
| 12.35 | Punch fingers | -- |
| 12.45 | Slush ore, which is running well because of blasts | 31 |
| 1.15 | Punch fingers | -- |
| 1.25 | Slush ore | 31 |
| 1.55 | Punch fingers | -- |
| 2.07 | Slush ore | 25 |
| 2.31 | Punch fingers (fingers packed and full of boulders) | -- |
| 2.45 | Slush ore | 20 |
| 3.05 | Punch remaining running fingers | -- |
| 3.22 | Slush drift clean of ore | 15 |
| 3.37 | Hang up cable | -- |
| 3.40 | Start out of the stope | -- |
| | Total | 280 |



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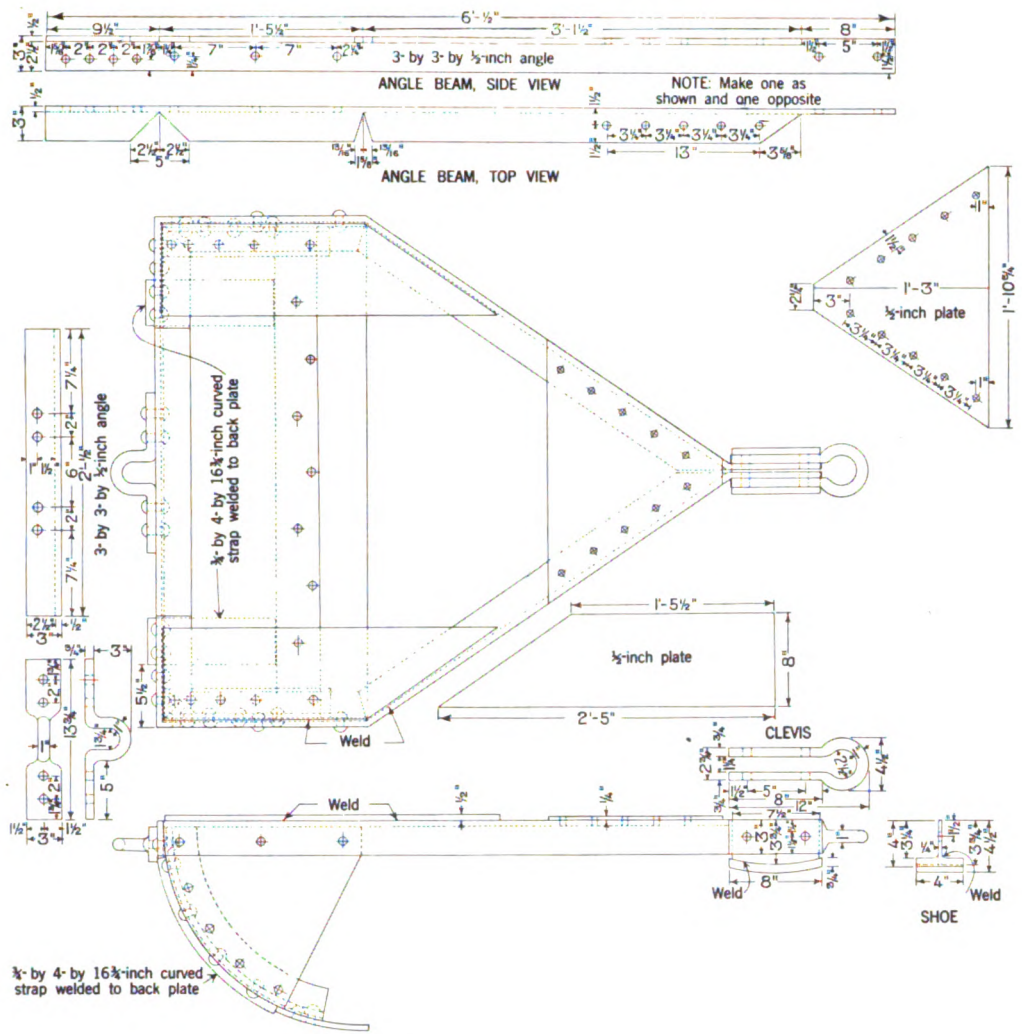
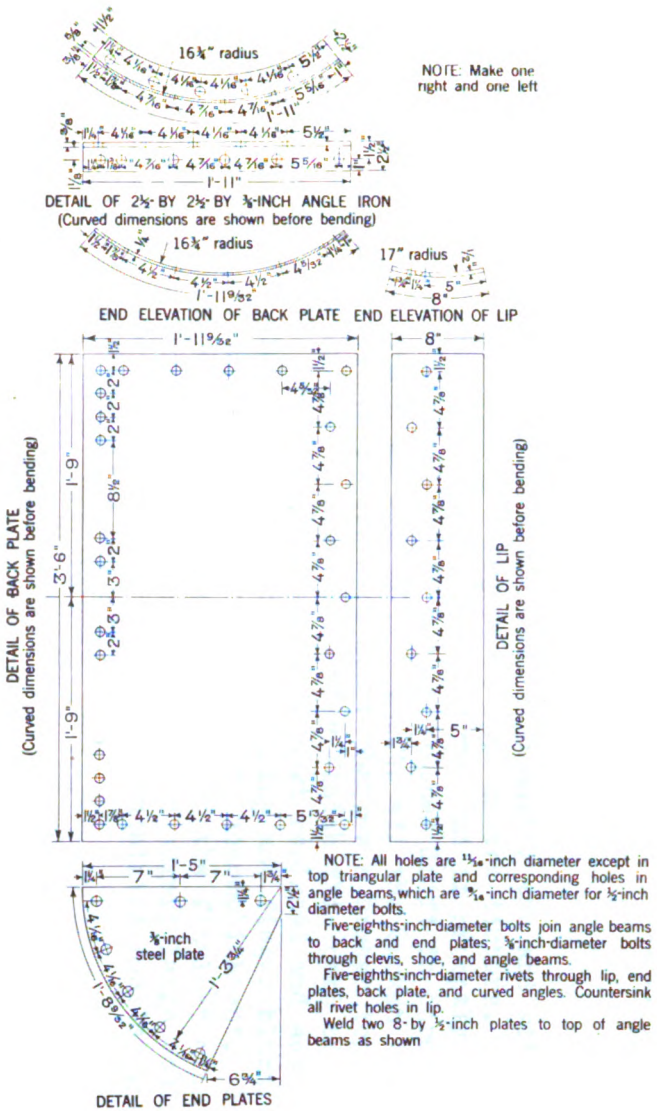

3- by 3- by ½-inch angle
ANGLE BEAM, SIDE VIEW
NOTE: Make one as shown and one opposite
ANGLE BEAM, TOP VIEW
3- by 3- by ¼-inch angle
⅜- by 4- by 16¾-inch curved strap welded to back plate
½-inch plate
Weld
CLEVIS
SHOE
⅜- by 4- by 16¾-inch curved strap welded to back plate

Figure 13.—Details of 42-inch scraper, Kimberley type.


16¾" radius
NOTE: Make one right and one left
DETAIL OF 2½- BY 2½- BY ⅜-INCH ANGLE IRON
(Curved dimensions are shown before bending)
16¾" radius
17" radius
END ELEVATION OF BACK PLATE
END ELEVATION OF LIP
DETAIL OF BACK PLATE
(Curved dimensions are shown before bending)
DETAIL OF LIP
(Curved dimensions are shown before bending)
⅜-inch steel plate
DETAIL OF END PLATES

NOTE: All holes are 13/16-inch diameter except in top triangular plate and corresponding holes in angle beams, which are 9/16-inch diameter for ½-inch diameter bolts.

Five-eighths-inch-diameter bolts join angle beams to back and end plates; ⅜-inch-diameter bolts through clevis, shoe, and angle beams.

Five-eighths-inch-diameter rivets through lip, end plates, back plate, and curved angles. Countersink all rivet holes in lip.

Weld two 8- by ½-inch plates to top of angle beams as shown

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## Slusher-Drift Repairs

The light or routine repair work consists of changing top and side lagging and removing ground where weight begins to show on the timbers. Light repairing is the most important work of the repairmen and if promptly taken care of heavy repairs may be avoided. To keep a slusher drift in condition so that no delays shall hinder the ore-pulling shift, all the broken top lagging must be changed daily. An experienced miner changes a broken top lagging in a few minutes; consequently, a crew can readily finish this part of its work in a half shift. The broken side lagging is next replaced and set back to keep the ground from the posts. The light repairing and finger blasting are routine, and no special orders are given for their accomplishment. Finger blasting is the last duty of a repair crew and occupies the final 45 minutes of their shift. The packed fingers are drilled by hand auger; large boulders are drilled with a hand-rotated stoper, and fingers containing smaller boulders are bombed. All shots are blasted going off shift.

Changing of broken posts, caps, or girts is termed heavy repair. If light repairs are kept up properly, heavy repairs are seldom necessary. Heavy repair, because of the danger of closing a slusher drift, is given preference. If a post, cap, or girt breaks the boss orders it changed immediately, and the squeezing ground or boulder that broke the timber is removed.

In slusher mining as practiced at the Emma Nevada mine it is essential that drifts be kept open for the daily draw. Experience has shown that a steady, uniform flow of ore from all draw points is necessary to prevent development of excessive weight on the extraction openings. If a drift is closed for heavy repairs at any point over a period of a few days, the drift timbers beyond that point invariably crush. The method used in maintaining the slusher drifts is most economical, as a small amount of light repairs at the proper time and place saves a great deal of heavy repair work later on.

## SLUSHING EQUIPMENT

The equipment best suited for slushing is an individual problem, depending on the character of ore and general slushing arrangements. Sixty percent of the ore mined at the Emma Nevada mine will pass a 1-inch screen and about 20 percent will pass 65 mesh. Large boulders are extremely rare, and a slusher drift often produces its daily quota of 300 tons with only 8 or 10 boulders showing that require breaking to pass the standard 11-inch grizzlies. On the other hand, the ore is sticky and abrasive.

### Scrapers

Although cast scrapers of various makes have been tried, it has been found that a hoe-type scraper designed and fabricated in the company shops is the cheapest and best for Emma Nevada ores. Figure 13 shows the essential details of this scraper. It is recognized that a heavier, sturdier type would be required for coarser material and under more adverse slushing conditions.



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## Ropes

Many different types of wire ropes have been used, and performance data have been recorded carefully. The best results have been obtained with 1/2-inch 6 by 19 preformed improved plow-steel ropes with hemp center. Broken ropes are spliced by men designated for this work, who are responsible for the general care and lubrication of the slushing equipment. Ropes are knotted only as a temporary measure, as a knotted rope piles up on a hoist drum, snags in the docks, and hastens wear and breakage.

## Hoists

The slusher hoists are double-drum electric tuggers of standard manufacture in 15- and 20-horsepower sizes. It is felt that compressed-air-driven hoists are not practicable for the large daily tonnages. Rope pull is 2,200 to 2,500 pounds. Loaded speed is 200 feet per minute on the 15-horsepower units and 280 to 300 feet per minute on the 20-horsepower units. The 20-horsepower units are used chiefly in the subslusher drifts, which serve an area 60 feet wide and produce twice the daily tonnage of a standard slusher drift. The 20-horsepower units handle 43-inch scrapers, while 42-inch scrapers are used with the 15-horsepower units. Ten-inch head blocks and 4-inch and 6-inch guide blocks are standard for the haul-back line.

## General

Slushing routine at the Emma Nevada mine offers no information as to what daily tonnages the slusher hoists could handle if continuous slushing were practiced. The actual operation is intermittent finger-drawing and slushing, and the tonnage to be drawn is governed by the rate at which the ore caves. The 15-horsepower units will handle 250 to 300 tons over an average slushing distance of 75 feet with an actual slushing time of 4 to 5 hours. The 20-horsepower units have handled 500 to 600 tons over an average distance of 75 feet in about 6 1/2 hours actual slushing time. These daily tonnages represent the rates dictated by proper draw control. The hoists and scrapers are not unduly large and operate satisfactorily in the slusher drifts, which are kept small in cross section to minimize repair costs.

## ADVANTAGES OF SLUSHER MINING

The chief advantages of slusher and subslusher methods of mining compared to conventional block-caving methods are represented by the savings in development expenditures. The development savings have ranged from 3 cents per ton to a high of 10.6 cents per ton. Maximum savings are made when the ore body is thin and high above the haulage level. These development savings do not include the material savings also made in main haulage drifts when slusher methods are used.

Figure 14 is a plan of the main haulage level. The area on the western portion of the map has been laid out for slusher mining and may be compared to the eastern portion, which was driven for conventional block-caving methods.



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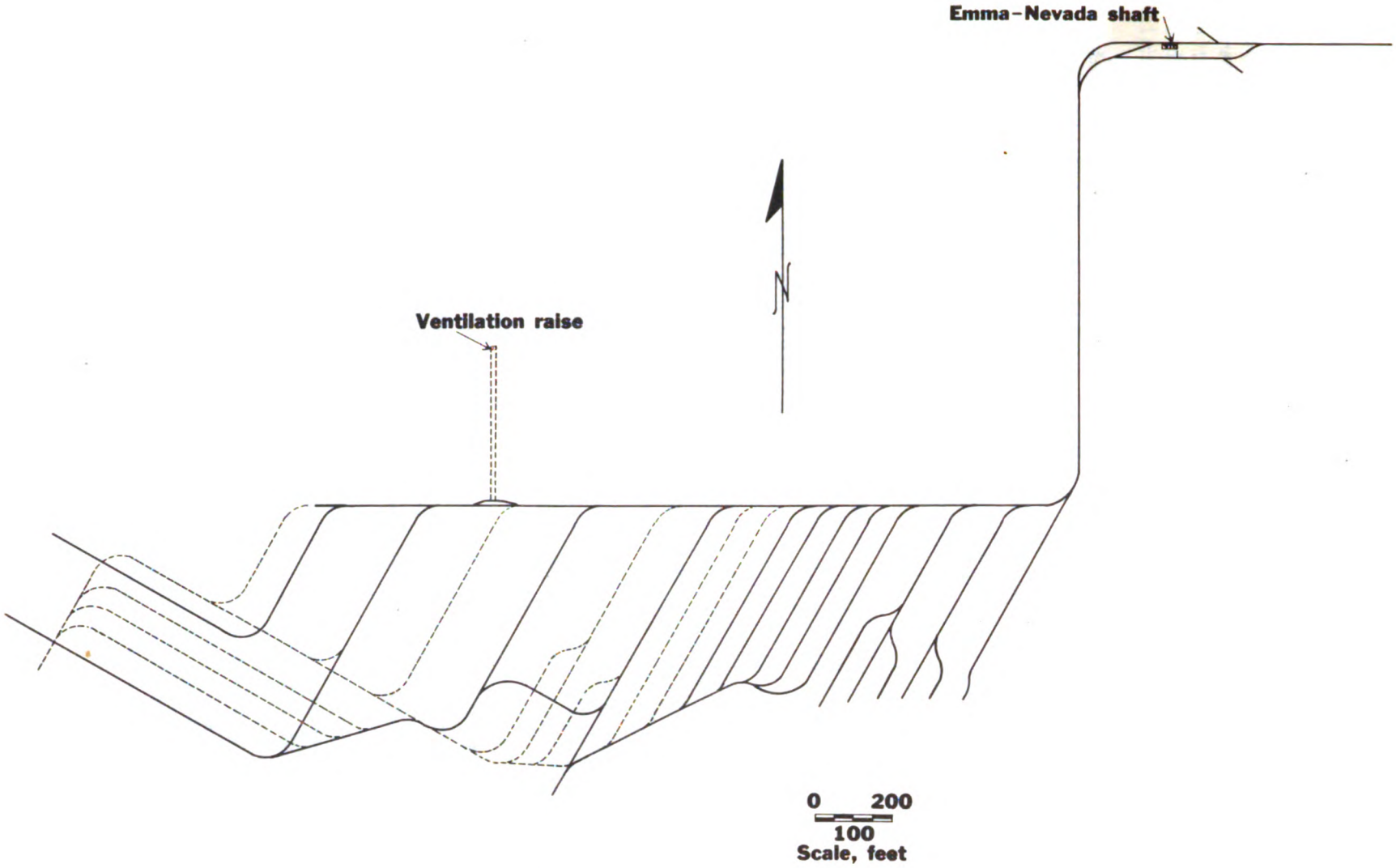


Figure 14.–Plan of main haulage level.

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The dotted lines represent drifts that, although necessary for conventional methods, are not needed when slushing methods are applied. The total footage of drifting saved by application of slusher methods is 7,000 feet, which would cost from $30 to $50 per foot, depending on ground conditions. With the decreased footage of haulage drifts and other development headings it follows that maintenance costs per ton will be reduced. The advantages in prospecting and mining fringe areas and the consequent beneficiation of ores that might otherwise be lost to mining have already been noted.

An important operating advantage of slusher mining is the ease of ingress and egress afforded by the development lay-out. Instead of climbing up and down ladders the mine bosses may now examine entire sections by merely walking through the slusher drifts. The 16 draw fingers and a slusher drift 120 feet long may all be examined in a much shorter time than would be required to climb into four individual square sets, as was necessary under the older practice. As a result, a boss can examine four or five times as great an area as heretofore, with much less physical exertion.

Draw control, the all-important factor, has been improved through better supervision. The samplers, control engineers, and bosses now see virtually all producing draw points daily, an almost impossible task when conventional block-caving methods are employed.

The slushing method insures a controlled draw, as fingers cannot "run wild." A chute puncher in a square-set can fill his raise from one finger that is running well, but in slusher mining, when all fingers have been drawn into the drift, he must slush the ore to the raise and then repeat the process.

Reference to the tabulation of an idealized slushing shift (p.12) will show that each finger must be drawn 8 or 9 times daily. This gives a much more uniform draw than by taking the entire day's quota from a finger all at once.

The ease of ingress and egress afforded by the development lay-out also aids better ventilation and makes delivery of timber and other supplies much easier and less expensive. Advantages in repair and maintenance are equally important. It is much easier to carry on repair and maintenance work in a drift than on the top of a 100-foot raise.

Incidentally, in one area in which the ores were particularly high-lying it was found advisable to drive a vertical raise from the main haulageway to the mining horizon to serve the slushing area as a supply and manway raise. The raise was equipped with an Otis elevator having a live-load capacity of 5,000 pounds. Connection drifts were driven from this raise to the various slushing drifts so as to serve the area with supplies and provide easy entrance for the workmen. The openings also provide better ventilation. This installation paid for itself before one-third of the ores in the area served had been mined.



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In slusher mining the number of raises from the main level to the mining horizon is about one-eighth those required in conventional block-caving. A smaller number of loaders and "chute knockers" is required for a given tonnage, and haulage problems are simplified, resulting in an appreciable saving in loading and haulage.

By using slusher mining methods, working conditions have been made safer in many respects. It is axiomatic that improvements in supervision and ventilation go hand in hand with safety. Horizontal mine openings with easily accessible connections are safer than raises, and the miners can aid fellow workmen much more quickly and with greater ease. Perhaps the greatest contribution slusher mining makes to safety is the fact that workmen are in closer contact with each other.

## COSTS

Since the inception of slusher mining, separate costs have been kept, where feasible, for conventional block-caving, slusher mining, and subslusher mining. A complete segregation of costs, however, has been wholly impracticable. Direct labor and supply costs are segregated, but loading and tramming charges are merely divided on a tonnage basis, resulting in the same recorded costs for the three methods. Total loading and tramming charges are between 8 and 9 cents for the entire mine, and time studies indicate that the amount of these charges properly attributable to slusher mining ranges from 6 1/2 to 7 1/2 cents. Improvements in ventilation, supervision, and delivery of timber when slusher methods are used are not reflected in the costs as recorded.

The men who operate the tuggers have many other duties common to both methods of mining. They draw the fingers, bomb and drill when necessary, and help keep the slusher drift and fingers in repair. It is impracticable to record the actual hours and minutes spent at each particular task, and for that reason the cost sheets do not reveal the exact cost of mechanically handling the ore. The total of such expense however, is included in the cost of "caving," which is between 11 and 12 cents per ton for all charges incident to drawing the fingers and slushing the ore to the raises. Studies indicate that the cost of actual slushing, including labor, power, cables and blocks, scrapers, maintenance of all equipment, and amortization of the hoists on a 2-year basis, does not exceed 4 cents per ton.

The following table shows comparative costs for the first 9 months of 1939. Cost of raises, control drifts and fingers, and undercutting does not show, since the amount expended depends merely on the amount of this work undertaken in a given period. The cost per ton for these items is also governed by the thickness of ore in the blocks being mined.



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Costs for first 9 months of 1939

| | Raise mining | Slusher mining | Subslusher mining | Total |
|---|---|---|---|---|
| Tons mined..... | 335,051 | 587,443 | 692,407 | 1,614,901 |
| Caving expense..... | $ 0.068 | $ 0.109 | $0.117 | $0.105 |
| Repairs..... | .068 | .072 | .084 | .076 |
| Loading..... | .019 | .019 | .019 | .019 |
| Tramming ..... | .063 | .063 | .063 | .063 |
| Hoisting..... | .033 | .033 | .033 | .033 |
| General mine expense | .109 | .109 | .109 | .109 |
| General expense and maintenance..... | .101 | .101 | .101 | .101 |
| Total..... | .461 | .506 | .526 | .506 |

Past records and estimates for future mining show a charge of 15 cents per ton for all development openings above the haulage level and about 6 cents for main-level development for the entire mine, which, when added to the 50.6 cents, gives a total cost per ton of 71.6 cents. This figure includes all items of corporate expense except capital charges for construction items and major equipment and income and bullion taxes. General expense items are high, as the ores are concentrated and smelted on a custom basis, leaving the mine only to bear general charges.

A true answer to the economy of slushing practice can not be gained without studying the development lay-out for each individual block. A block mined by slusher methods may show a cost per ton higher than a neighboring block mined by raises, because the ores were thin and high above the level with resulting high development charge; yet material savings may have been effected.

In analyzing the cost tabulation above it must be remembered that the standard raise-mining methods were carried on in areas where the ore-body bottom was at an ideal distance above the haulage level (approximately 60 feet) and where the ore was of greater than average thickness. Apart from the obvious effect of lower development costs per ton, slusher mining will lead in many other ways to cheaper mining costs. Attention is called to the fact that slusher mining has been used in places where the less favorable conditions exist, such as thinner fringe areas and areas where the ore is high above the level.

The following tabulation shows some efficiency data of general interest for the period from January through September 1939:



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| | |
|---|---|
| Dry tons ore mined: | |
| Raise mining | 335,051 |
| Slusher mining | 587,443 |
| Subslusher mining | 692,407 |
| Total | 1,614,901 |
| Feet advanced: | |
| Standard raises | 2,223 |
| Slusher raises | 1,143 |
| Subslusher raises | 5,669 |
| Slusher drifts and fingers | 3,867 |
| Subslusher drifts | 868 |
| Main-level drifts | 3,342 |
| Prospect raises | 729 |
| Prospect drifts | 101 |
| Total square feet undercut | 143,400 |

| | Shifts | Tons per shift |
|---|---|---|
| Total gross payroll | 120,931 | 13.3 |
| Charged mining and development | 114,302 | 14.1 |
| Underground 1/ | 80,297 | 20.1 |
| RAISE MINING: | | |
| Caving | 3,141 | |
| Raise repairs | 2,296 | |
| Total | 5,437 | 61.6 |
| SLUSHER MINING: | | |
| Caving | 6,364 | |
| Raise-drift-finger repairs | 4,299 | |
| Total | 10,663 | 55.1 |
| SUBSLUSHER MINING: | | |
| Caving | 7,807 | |
| Raise-drift repairs | 6,124 | |
| Total | 13,931 | 49.7 |
| Total | 30,031 | 53.8 |
| Loading | 4,302 | |
| Tramming 2/ | 11,198 | |
| Drift repairs (main level) | 2,636 | |
| Hoisting | 5,130 | |
| Total | 23,766 | 68.0 |



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| | Shifts | Ft. Per Shift |
|---|---|---|
| Total undercutting ..... sq. ft.. | 1,700 | 0.84 |
| Standard raising..... | 1,437 | 1.55 |
| Slusher raising..... | 1,352 | .85 |
| Subslusher raising..... | 3,147 | 1.80 |
| Slusher drifts and fingers..... | 2,930 | 1.32 |
| Subslusher drifts..... | 730 | 1.19 |
| Main-level drifting..... | 4,346 | .77 |
| Prospect raises ..... | 314 | 2.32 |
| Prospect drifts ..... | 128 | .79 |

| | Shifts |
|---|---|
| Underground timber delivery ..... | 2,586 |
| Cleaning mine, roustabouts ..... | 2,501 |
| Railroad car loading, waste disposal, surface tracks, maintenance, ore bins..... | 1,951 |
| Drill, tugger, shovel repairmen, pipemen, and nippers ..... | 4,902 |
| Sampling and engineering..... | 1,995 |
| Tool sharpening, powdermen, janitors ..... | 1,802 |
| Bosses, safety first, miscellaneous ..... | 4,180 |
| Mine trucking ..... | 509 |
| Timber framing ..... | 2,001 |
| General and distributable charged mine (shops and surface).. | 21,994 |

PERCENT COST ELEMENTS TO OPERATING COST[1/]:

| | |
|---|---|
| Labor..... | 49.6 |
| Supplies ..... | 19.0 |
| Power ..... | 2.3 |
| Distributable ..... | 6.8 |
| Compressor ..... | 3.2 |
| Deferred ..... | 3.6 |
| Unclassified ..... | .1 |
| General expense..... | 15.4 |

TIMBER DATA:

| | |
|---|---|
| Board feet timber per ton ore, total repairs..... | .49 |
| Board feet timber per ton ore, total consumption... | 1.87 |

EXPLOSIVES DATA:

| | |
|---|---|
| Powder per ton ore, total consumption..... pounds | .13 |

MISCELLANEOUS:

| | |
|---|---|
| Kw.-hr. per ton ore, mining..... | 4.02 |
| Kw.-hr. per ton ore, total plant consumption..... | 4.55 |
| Kw.-hr. per ton ore, electric tuggers..... | .32 |
| Compressor cost per ton ore ..... | .024 |

1/ All men working underground, including car repairmen, underground electricians, and all mine bosses. Excludes hoistmen, topmen, framers, car loaders, dryhousemen, watchmen, firemen, compressormen, and three mine-office employees.

2/ Includes motormen, helpers, grizzlymen, track repairmen, and men engaged in maintenance of motors, trolleys, etc.



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